FIVE TO 10 MA EXPERIMENTS USING FLAT PLATE EXPLOSIVE GENERATORS[*]

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Abstract

High explosive pulsed power (HEPP) techniques can address a wide range of pulsed power needs. The basis for HEPP techniques is the use of high explosives to reduce the inductance of a current-carrying circuit, thus multiplying the current due to magnetic flux conservation. For the past twenty years at Los Alamos, our high energy density physics (HEDP) program has followed a path leading to more sophisticated and higher current (and often power) systems. Twenty years ago, we had the capability of conducting tests at 10, or even 30 MA, with no power conditioning and low inductance loads. The time scale of the experiment was the time it took to compress the flux explosively, and our fastest generator with high current capability was a plate generator [1]. The operating time of the generator is less than 15 μs, and flux loading requires either an additional ~60 μs or a reduced-efficiency inductive coupling scheme. We could also deliver shortened pulses to select loads by completing our generator circuit, initially, with a relatively high inductance circuit element, then switching in a lower inductance with 2-3 μs left of the generator pulse. Figure 1 shows the results of such a test. The test was conducted in 1974 to investigate our capability to drive plasma z-pinch experiments for the production of soft x-rays [2], and was a pulsed power success. However, our understanding of vacuum power flow issues was not mature enough at that time to design a functioning plasma z-pinch load.

There was a renewed need for such a system in ~1980, and at that time we began assembling a complete set of techniques required for success. We first fielded a baseline test using a simplified version of the HEPP system that generated the Figure 1 data. Subsequent tests followed a "bite size" philosophy. That is, we first designed a complete system for a level of complexity at which we believed success could be achieved. We conducted tests of that system, and once it was working in all respects, we designed the next generation system. The ultimate goal of this process was to develop a source of ~1 MJ of soft x-rays. The process culminated, after the development of two intermediate level systems [3,4], with the development of the Procyon system [5]. This system
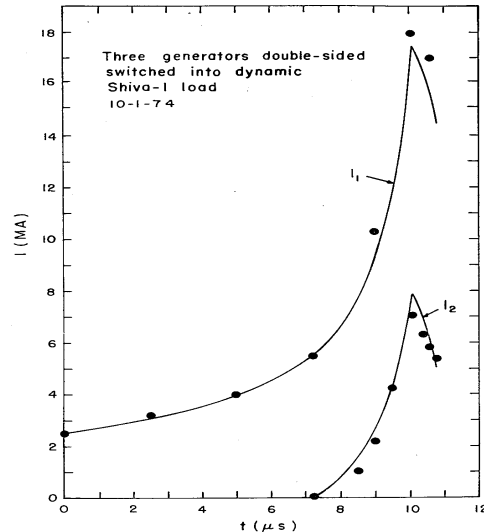
Figure 1. Currents for a short-pulse plate generator experiment. For this test, three plate generators were used in parallel. I_1 and I_2 are generator and load currents respectively.

produced x-ray pulses of up to 1.7 MJ at temperatures up to 97 eV [6].

Following those experiments, our attention turned to powering solid-density z-pinch liners, requiring even higher current systems. At Los Alamos, we developed the Ranchero system [7] for that purpose, and we have collaborated with HEPP experts in Russia [8] to power similar liner loads using disk generator systems. Our Ranchero system includes a module tested at ~50 MA, that should operate easily at 70-90 MA. We designed Ranchero to allow modules arrayed in parallel to generate currents over 200 MA, and we are confident that we can do experiments now at 50-200 MA in the same way that we could do tests at 10-30 MA with plate generators 20 years ago.

We have recently stepped back from our quest for higher energy and power systems to consider what applications we can address using relatively low cost plate generators coupled with advances achieved in our HEDP system development. We will describe relevant HEPP components, and discuss two promising applications.

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14. ABSTRACT
High explosive pulsed power (HEPP) techniques can address a wide range of pulsed power needs. The basis for HEPP techniques is the use of high explosives to reduce the inductance of a current-carrying circuit, thus multiplying the current due to magnetic flux conservation. For the past twenty years at Los Alamos, our high energy density physics (HEDP) program has followed a path leading to more sophisticated and higher current (and often power) systems. Twenty years ago, we had the capability of conducting tests at 10, or even 30 MA, with no power conditioning and low inductance loads. The time scale of the experiment was the time it took to compress the flux explosively, and our fastest generator with high current capability was a plate generator [1].

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I. HEPP COMPONENTS

A. Plate Generators

Plate generators have been described many times, but we give a brief description here for completeness. Figure 2 shows the side view of a typical plate generator. The device consists of two plates that are driven explosively towards each other. The high explosive is detonated simultaneously over its surface, so that each plate moves perpendicular to its original plane. We typically include some taper from the input to the output end. This provides two advantages. The first is that it provides a
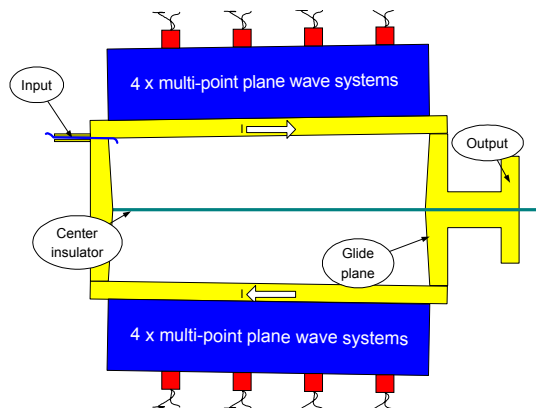

Figure 2. Side view of plate generator. Typical device is 530 mm long and 133 mm wide. Output separation ~130 mm, and input separation varies according to need.

margin of error against the output of the generator closing prematurely. The second is that some control on the output voltage can be achieved in this way. By increasing the taper, the voltage near the end of the generator run is reduced. For highest voltage output requirements (as for instance driving the primary of a transformer), we use the least taper practical, which has been experimentally determined to be 120mm:127mm, input separation:output separation. For current generation into relatively high inductance loads, on the other hand, we find a ratio of 102mm:130mm to be a good choice. Plate generators are typically ~133 mm wide, and as a result are limited to currents not greatly exceeding 13 MA. A typical plate generator current profile is shown in Figure 3.

B. Explosively Formed Fuses

One device developed in our HEDP program is the explosively formed fuse (EFF) opening switch. We have also published many results from tests of these devices [5]. EFF's can carry large currents (e. g. >20 MA in the Procyon system) with minimal loading of the circuit, then increase to substantial resistance values on the time scale of 1-2 µs. We have shown in the last few years that there is some control of the resistance profile, and hence the voltage waveform it generates. Figure 4 shows typical resistance profiles determined from small-scale planar

devices. Most applications are in coaxial configurations, but scaling to cylindrical EFF's from planar data works reasonably well. In the recent development of small diameter devices (~100mm) [9], we have found a bigger
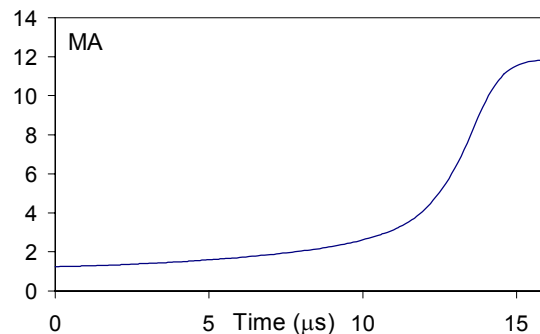

Figure 3. Typical plate generator current profile. Flux compression begins with 1.25 MA flowing in circuit. This result is for a 15 nH inductance load.
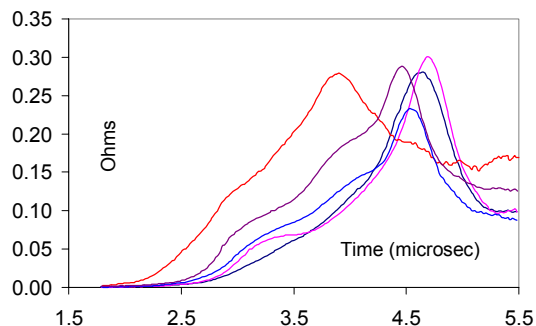

Figure 4. Resistance curves for a few EFF experimental configurations. Resistances scale to other dimensions by simple length/width relationships.

difference in scaling than in previous large diameter (~340 mm) systems, owing presumably to the larger expansion ratio in the smaller diameter apparatus.

C. Plasma Compression Switches

Another device that can now be revisited is the plasma-compression-opening switch, first published by Pavlovskii [10]. In our first stage of z-pinch system development, we adapted the coaxial geometry shown by Pavlovskii to a planar version because, at that time, we did not have an adequate cylindrical detonator. We achieved good success with our version [11], but it was limited to ~1.5 TW operating power.

Since that time, for both generator and opening switch needs, we have developed cylindrical detonators up to 1.4 m in length, that are completely suitable for coaxial plasma flow switch experiments. These switches offer the potential of a faster resistance rise than available from EFF switches, and for experiments in the 10 MA range, sizes of interest could be easily built. In 1985, we

conducted one cylindrical test with a plate generator and our first 15 cm-long cylindrical detonator. Based on those results, better voltage management skills we have developed, and present detonation systems, we could design systems operating at ~10 MA and several hundred kilovolts. Considering coupling such a switch with a Ranchero generator to operate at even higher currents and voltages is beyond the scope of this paper, but would lead to very interesting results.

II. ISENTROPIC COMPRESSION EXPERIMENTS

One application that we are currently working on is the combination of a plate generator and an EFF to provide the wave shape necessary for isentropic compression experiments (ICE). Tasker [12] presents a paper on our ICE work in this conference, and for details, we refer the reader to that paper. Briefly, we expect to generate currents of 10-13 MA in an EFF opening switch. The EFF should open to ~150 kV, and staged closing switches provide wave shaping for the load current. In initial tests, the copper load requires a slow rising (~300ns) initial foot, then a fast rise to the largest possible current. Present goals are to achieve currents with this profile that peak at 8 to 10 MA. This should provide isentropic compression data for Cu at pressures up to 2MB. Ultimate goals are to conduct these tests at pressures up to 25 MB using currents available from Ranchero generators.

III. THETA COIL EXPERIMENTS

While pursuing the ICE design concept, we realized that there was another exciting possibility for using plate generators to achieve conditions needed in HEDP experiments [13]. Plate generators naturally adapt to theta coil output configurations, and current densities needed to achieve high liner implosion velocities are available. Time scales for such experiments are not demanding, and very interesting experiments can be performed without using opening switches; in fact in the same configuration as the experiment of Figure 1. Figure 5 shows side and end views of a load for such an experiment. Current in the theta coil induces current in an enclosed liner, and the induced current implodes it. The circuit for this experiment is shown in Figure 6. We have developed a model to simulate these implosions. The model attempts to predict the imploding liner velocity profile and its effect on the driving circuit with some accuracy. From numerical models that include finite-length coil effects, the model calculates L_p, L_s, and M as functions of liner radius. Liner acceleration is calculated simply from F=ma. Ultimately design considerations regarding parameters such as end effects and material strength will be needed. For now we have a good predictive capability. Preliminary calculations used theta coils 50 mm in diameter and both 5 and 10 cm wide. We assume 1mm
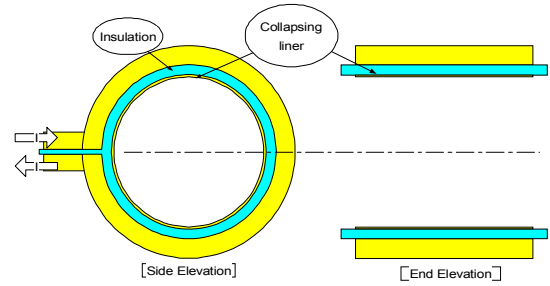

Figure 5. Theta coil load. Transmission line in and out from left attaches to a plate generator through a closing switch.

insulation between the coil and the liner, and that we should leave ~25 mm free space inside the liner for diagnostics. Either larger or smaller diameter systems are easily considered, although reducing the diameter reduces
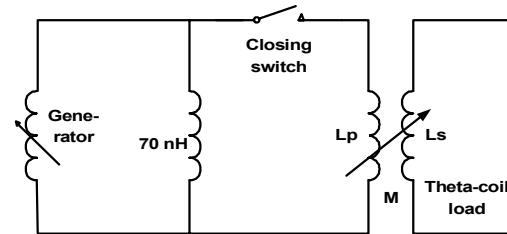

Figure 6. Circuit for Theta coil experiments. The 70 nH inductor completes the circuit during initial field loading from a capacitor bank (not shown) and the closing switch allows current to flow to the load at the desired time.

the diagnostic volume. Figure 7 shows the velocity profile for liners driven by 5 and 10-cm wide coils. Both liners start out 1 mm thick, with a mass of 20 g for the 5 cm coil, and 40 g for the 10 cm coil. We are just beginning to explore the useful parameter space, and the actual liner parameters chosen will depend on the physics experiment that we desire to perform. The velocity of the coil is very interesting as it stands, and reducing the width will further increase the velocity. The absence of glide planes (in contrast to z-pinch configurations) at the imploding coil ends allows free access for axial diagnostics, and there is no sliding contact to produce arcing or instabilities. This, combined with portability and low cost, makes this system a good candidate for a variety of HEDP applications.

V. CONCLUSIONS

Techniques developed over a 20 year span to pursue HEDP goals can be coupled with plate generators, which have been available since the early 1970's. The relatively low cost systems can be applied to meet some current needs. We are currently using EFF opening switches and plate generators to perform ICE experiments, and we
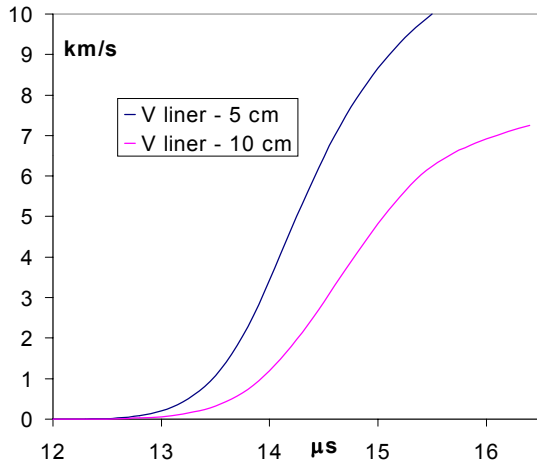
Figure 7. Velocity for liners imploded by 5 and 10 cm wide theta coils. The calculation cuts off when the liner reaches 25.4mm radius.

propose using plate generators to power theta coil experiments that can answer a variety of high energy density physics questions. We have developed a model for accurate current, and load-velocity predictions, that allows us to scope out the capability of the technique.

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